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RESEARCH MEMORANDUM

SOME OBSERVATIONS ON LOSS OF STATIC

STRENGTH DUE TO FATIGUE CRACKS

By Walter Illg and Herbert F. Hardrath

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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TESTS AND SPECIMENS

The specimens were $2\frac{1}{4}$ inches wide and they had a free length of 12 inches between grips. Two semicircular notches with a $\frac{3}{8}$-inch radius were used to aid crack initiation. The net width in the test section was 1.5 inches. Four materials were tested: 2024 and 7075 aluminum alloys in both sheet and extruded forms.

The sheet material was 0.075 inch thick and the extruded material was 0.125 inch thick. The specimens were subjected to repeated axial tensile loads producing average net section stresses not greater than 35,000 pounds per square inch. At least 100,000 cycles were required to produce cracks of the desired length. The cracks were measured prior to static test with the aid of a toolmaker's microscope. Inspection of the surface after failure revealed a sharp contrast between fatigue-cracked and statically failed sections and indicated that the cracks had been measured with less than 1-percent error. More elaborate methods of checking crack depths were, therefore, not used. The specimens were then subjected to static test to determine the remaining static tensile strength. The maximum tensile load was reached after necking occurred at the ends of the cracks but before the crack lengths increased to a noticeable extent. Since the crack proceeded from only one side of a specimen in nearly all cases, the static load was eccentric with respect to the remaining material. The effect of this eccentricity on the results will be discussed subsequently.

RESULTS AND DISCUSSION

Figure 2 presents some of the results obtained in tests of 7075-T6 sheet specimens. The ordinate is the static strength of a cracked specimen expressed as a percentage of the static strength of an uncracked specimen. The abscissa is the percent of the original area remaining. The dashed line represents the strength of a cracked specimen based on the assumption that the loss of strength is equal to the loss of area. The symbols represent test points. The loss of static strength was found to be much greater than the loss of area over the complete range of the tests. The effect is most marked in the early stages of crack growth. For instance, when the net section was reduced to 90 percent, the strength was reduced to 50 percent.

A similar plot (fig. 3) presents a comparison between results of tests on 2024-T4 and 7075-T6 extrusions. The curve for 7075-T6 is essentially the same as that shown previously for 7075-T6 sheet; similarly, the curve for the 2024-T3 sheet is essentially the same as that

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SOME OBSERVATIONS ON LOSS OF STATIC STRENGTH DUE TO FATIGUE CRACKS

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SUMMARY

Static tensile tests were performed on simple notched specimens containing fatigue cracks. Four types of aluminum alloys were investigated: 2024-T3 (formerly 24S-T3) and 7075-T6 (formerly 75S-T6) in sheet form, and 2024-T4 (formerly 24S-T4) and 7075-T6 (formerly 75S-T6) in extruded form. The cracked specimens were tested statically under four conditions: unmodified and with reduced eccentricity of loading by three methods. Results of static tests on C-46 wings containing fatigue cracks are also reported.

It was found that the static strength of 7075 aluminum alloy was somewhat more sensitive to fatigue cracks than was that of 2024 aluminum alloy. There was little difference between the behavior of extruded and sheet material in the same alloy. In cases where the eccentricity of loading was minimized, the effective stress-concentration factor for a fatigue crack at static failure was approximately 1.33. The built-up wing structure was found to have somewhat better strength properties than single-element parts for two reasons: (1) the adjoining structural elements provided restraints which minimized the eccentricity of loading on the failing section; and (2) the load was probably redistributed among the various elements during progressive failure in the wing.

INTRODUCTION

One problem of practical interest which arises as the result of the formation of a fatigue crack of finite size is the prediction of the static strength of a member containing such a crack. Certain failures of aircraft in service and a very limited laboratory investigation indicated very serious loss of static strength due to small fatigue cracks. Other than this, information pertinent to this problem in aircraft structural materials is very sketchy.

In order to provide such information, the Structures Research Division of the Langley Aeronautical Laboratory has begun a systematic study of loss of static strength due to fatigue cracks in simple specimens. Figure 1 shows the configuration of the specimens used in this investigation.

TESTS AND SPECIMENS

The specimens were $2\frac{1}{4}$ inches wide and they had a free length of 12 inches between grips. Two semicircular notches with a $\frac{3}{8}$-inch radius were used to aid crack initiation. The net width in the test section was 1.5 inches. Four materials were tested: 2024 and 7075 aluminum alloys in both sheet and extruded forms.

The sheet material was 0.075 inch thick and the extruded material was 0.125 inch thick. The specimens were subjected to repeated axial tensile loads producing average net section stresses not greater than 35,000 pounds per square inch. At least 100,000 cycles were required to produce cracks of the desired length. The cracks were measured prior to static test with the aid of a toolmaker's microscope. Inspection of the surface after failure revealed a sharp contrast between fatigue-cracked and statically failed sections and indicated that the cracks had been measured with less than 1-percent error. More elaborate methods of checking crack depths were, therefore, not used. The specimens were then subjected to static test to determine the remaining static tensile strength. The maximum tensile load was reached after necking occurred at the ends of the cracks but before the crack lengths increased to a noticeable extent. Since the crack proceeded from only one side of a specimen in nearly all cases, the static load was eccentric with respect to the remaining material. The effect of this eccentricity on the results will be discussed subsequently.

RESULTS AND DISCUSSION

Figure 2 presents some of the results obtained in tests of 7075-T6 sheet specimens. The ordinate is the static strength of a cracked specimen expressed as a percentage of the static strength of an uncracked specimen. The abscissa is the percent of the original area remaining. The dashed line represents the strength of a cracked specimen based on the assumption that the loss of strength is equal to the loss of area. The symbols represent test points. The loss of static strength was found to be much greater than the loss of area over the complete range of the tests. The effect is most marked in the early stages of crack growth. For instance, when the net section was reduced to 90 percent, the strength was reduced to 50 percent.

A similar plot (fig. 3) presents a comparison between results of tests on 2024-T4 and 7075-T6 extrusions. The curve for 7075-T6 is essentially the same as that shown previously for 7075-T6 sheet; similarly, the curve for the 2024-T3 sheet is essentially the same as that

for extrusion shown in figure 3. The strength of the 2024 materials appears to have been reduced somewhat less than the strength of the 7075.

In contrast to these tests on simple specimens, the Loads Calibration Section of the Langley Aeronautical Laboratory has performed static tests of C-46 wings which were subjected to fatigue loading until varying amounts of tension material had been failed. The results of these tests are presented in figure 4. In this figure the static strength of the wing containing no fatigue cracks is the strength of the wing as estimated for a tensile failure. One specimen, containing a crack which removed 3 percent of the tension material in the critical cross section, failed by buckling of the compression cover at a load 8 percent lower than that predicted for tensile failure in a new wing. The remaining specimens failed in tension, and for cracks penetrating less than 30 percent of the material, the reduction in strength is approximately equal to that which would be predicted by loss of area alone. These results contrast sharply with the results of tests on simple specimens previously described.

In figure 4, the points with tails represent cases where the crack had produced failure of a substantial portion of the tensile area. This large loss of structural material causes a large increase in the eccentricity of loading and a large decrease in the section properties of the wing. When such radical structural changes are considered, the large deviations in residual strength of the C-46 wings containing large cracks from the predicted values based on a simple analysis, represented by the dashed line, are probably to be expected.

Two important differences in test conditions appear to be among the factors responsible for the greater strength of the C-46 wings containing cracks less than 30 percent. First, in the simple specimens the fatigue crack was almost always initiated on only one side of the specimen and this crack generally grew during the static test. The resulting eccentricity of loading undoubtedly contributed to the reduction in the static strength. For small cracks in the C-46 wing, the eccentricity of loading on the failing section is minimized by a very large effective moment of inertia to resist bending in the plane of the cover; therefore somewhat better strength might be expected. Second, in the case of the C-46 wing with small cracks, whenever a given element fails, the load it carried may be shared by other elements which do not contain fatigue cracks. Depending upon the relative stiffnesses of the various elements, the remaining parts may carry more load than they were carrying previously. In the simple specimens, the stress is shifted to the neighboring material, but a very high stress concentration as a result of the crack is still present.

The effect of eccentricity of loading in simple specimens was studied by modifying specimens containing fatigue cracks in such a way

that the bending stress on the failing section was at least partially eliminated. This was accomplished in three ways as shown in figure 5.

The first sketch of the figure shows an unmodified specimen containing a fatigue crack. In the specimens illustrated by the second sketch, material was removed from the cracked side of the specimens so that the depth of the crack was equal to the depth of the notch on the other side. The third sketch illustrates those specimens in which a cut was made with a fine jeweler's saw to simulate a crack on the side opposite the fatigue crack. For this case, the net area is defined as the area remaining after the saw cut was made. Finally the fourth sketch shows the specimens shortened to 4 inches between the grips instead of 12 inches as in the other specimens.

The results for 2024-T3 sheet are shown in figure 6. The circles in this figure represent tests on unmodified specimens, and the triangles, squares, and diamonds represent tests in which the specimens were modified as indicated by the sketches and symbols in figure 5 to reduce eccentricity of loading and thereby the bending stress on the failing section. The results of these three series of tests are essentially the same and show a significant improvement in strength over most of the range of the tests. The dashed line was computed on the assumption that the stress on the failing section was 75 percent of the original ultimate tensile strength. In other words, it appears that the effective stress-concentration factor of a fatigue crack at static failure was about 1.33. The greater reduction of strength for the unmodified specimens was evidently due to the bending stresses set up by unsymmetrical loading. This eccentricity was less important for small cracks than for large ones, and the tests indicated equivalent strengths for the small cracks.

SUMMARY OF RESULTS

Although the tests performed to date are not sufficient to arrive at definite relationships for loss of static strength, the following qualitative conclusions seem justified. The static strength of 7075 aluminum alloy was somewhat more sensitive to fatigue cracks than was that of 2024 aluminum alloy. There was little difference between the behavior of extruded and sheet material in the same alloy. In cases where the eccentricity of loading was minimized, the effective stress concentration for a fatigue crack under static load was approximately 1.33. A complex structure is likely to have somewhat better strength properties than single-element parts for two reasons: (1) the adjoining structural elements usually provide restraints which minimize eccentricity of loading on the failing section, and (2) the load is probably redistributed among the various elements during progressive failures.

The extension of the quantitative observations discussed here to other cases should not be done without extreme caution. There is some unpublished evidence that other configurations, especially wider sheet specimens, exhibit considerably greater reductions in strength.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 13, 1955.

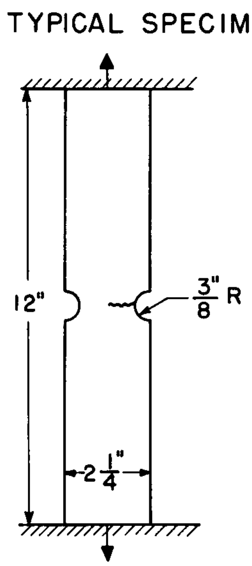

Figure 1

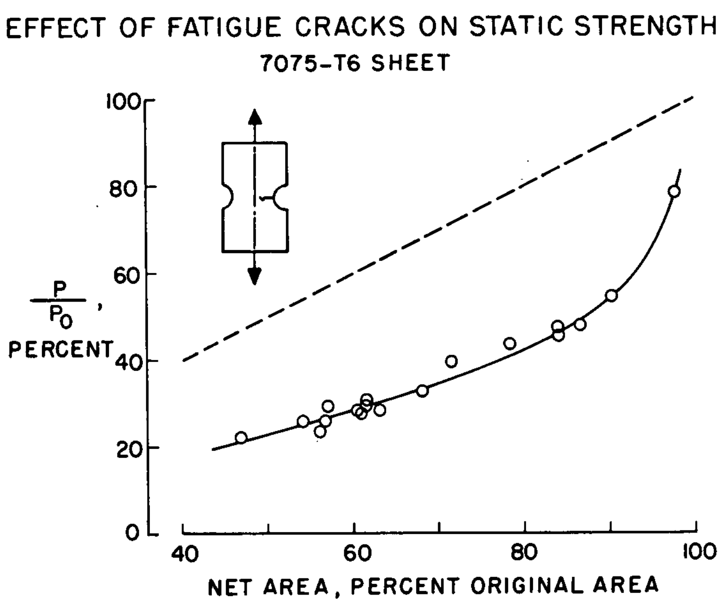

Figure 2

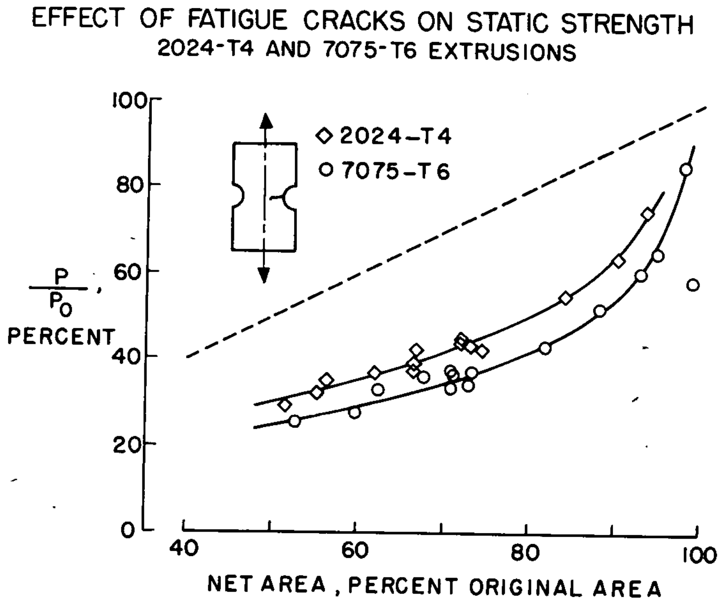

Figure 3

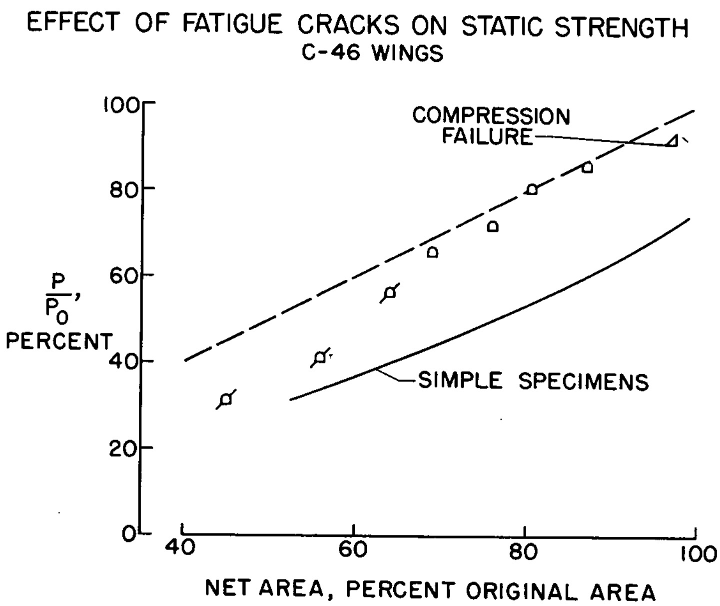

Figure 4

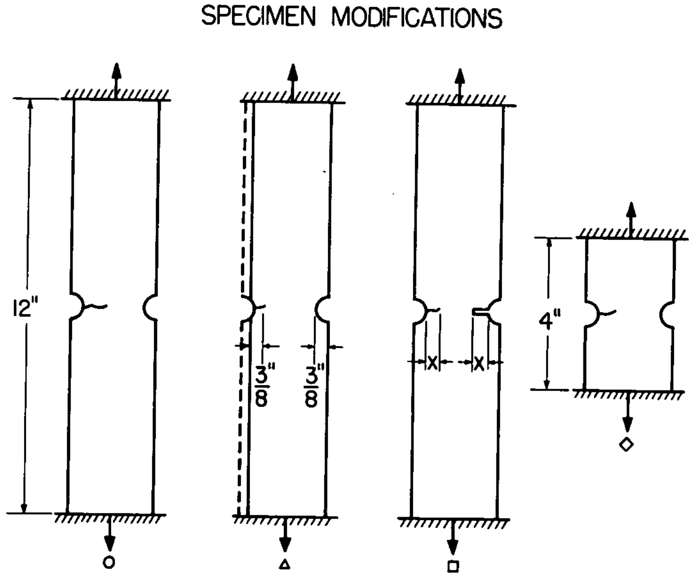

Figure 5

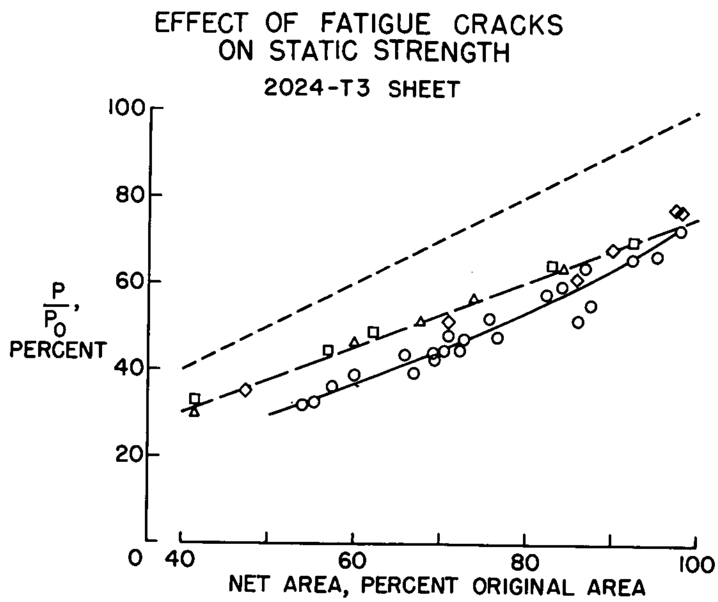

Figure 6